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Dynamic System Model of Land Use Affected by Sea Level Rise in the Coastal Area of Bengkulu City, Indonesia

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Abstract: Bengkulu City is the capital of Bengkulu Province, a coastal area with a coastline of ± 17.22 km. Sea level rise (sea level rise) will reduce coastal areas' function and cause flooding in coastal regions, erosion on sandy beaches, and damage to infrastructure near the coast. This research was conducted to provide a dynamic description of the inundation distribution due to various sea-level rise scenarios. This high population growth increases the need for space and land, impacting the decreasing carrying capacity. It is necessary to predict the availability of land; the area is built using a dynamic system model. The analysis of tidal data from the Pulau Baai Tidal Station for ten years of observation (2009-2018) shows a trend of sea-level rise in the coastal waters of Bengkulu City, which is around 0.82 cm/year. The development of developed land was observed through a dynamic system model of the relationship between population growth and land availability in 2008-2300. The prediction results of the model show that the affected area of land use in areas prone to sea-level rise has a directly proportional relationship to the year of land use development. It is inversely proportional to the availability of land; as the number of years and land use increases, the availability of land will decrease.

Keywords: Sea Level Rise, Dynamic System, Bengkulu, Land Use, Inundation

印度尼西亞 Bengkulu 市沿海地區受海平面上升影響的土地利用動態系統模型。

摘要：Bengkulu 市是 Bengkulu 省的首府，沿海地區的海岸線為±17.22 km。海平面上升（海平面上升）將削弱沿海地區的功能，並可能引起沿海地區的洪水，沙灘侵蝕以及沿海地區基礎設施的破壞。進行這項研究是為了動態描述由於海平面上升的各種情況而造成的淹沒分佈。如此高的人口增長增加了對空間和土地的需求，這可能會降低環境的承載能力，因此有必要預測土地的可利用性，該區域是使用動態系統模型構建的。根據對 Pulau Baai 潮汐站進行 10 年觀測（2009-2018 年）的潮汐數據分析，表明班古魯市沿海水域存在海平面上升的趨勢，約為 0.82 厘米/年。通過動態系統模型觀察了發達土地的發展，該模型在 2008-2300 年期間人口增長與土地可利用性之間存在關係。該模型的預測結果表明，在海平面容易上升的地區，受影響的土地利用面積具有與土地利用發展年份成正比的關係。這與土地的可利用量成反比，隨著年限和土地使用量的增加，土地的可利用量將減少。

关键词：**海平面上升**，**動力系統**，Bengkulu，**土地利用**，**淹沒**

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1. Introduction

Bengkulu City is one of the administrative areas which has quite a sizeable coastal district. In general, the resources of the coastal areas in this area have not been managed and utilized optimally and even have not carried out a systematic and sustainable inventory.

Land use in coastal areas tends to be more oriented towards economic principles and does not consider the principles of sustainability and land carrying capacity. The coastal area is an area where human activities are mainly carried out; even according to MacDonald [1], about 70% of the world's population lives in coastal areas, thus making this area concentrated in various centers of economic activity such as fisheries, tourism, transportation, industry, housing, defense and security [1], [2].

The coastal area is an area where human activities are mostly done. Even according to MacDonald (2005), about 70% of the world's population lives in coastal areas, thus making this area concentrated in various centers of economic activity such as fisheries, tourism, transportation, industry, settlement, defense, and security [1], [2]. Coastal areas are very vulnerable to the impact of rising sea levels. The causes of sea-level rise are melting polar ice caps, extreme climate change (global warming), and lowering land surface. Inundation of areas that are the economic centers of the surrounding community will result in huge losses, but different for each land use. Coastal areas are closely related to the physical conditions in the sea, one of which is the effect of rising sea levels on the site. Sea level rise is a phenomenon of rising sea level, which is influenced by climate. Sea level rise, which impacts shoreline retreat and inundation, can indirectly impact the lives of the surrounding community.

Based on the geographical conditions, the coastal area of Bengkulu City is very vulnerable to the impact of sea-level rise because it has flat coastal topography. Sea level rise (sea level rise) will reduce coastal areas' function and cause flooding in coastal regions, erosion on sandy beaches, and damage to infrastructure near the coast. Therefore, it is necessary to plan for disaster mitigation-based development. One of them is by knowing the impact of sea-level rise. The inundation distribution and its effects can be predicted and evaluated using the geospatial information system (GIS) and the Digital Elevation Model (DEM). It is hoped that this dynamic system modeling can help policies for future spatial planning for Bengkulu province.

Dynamic system modeling is based on the relationship between dynamic population growth and land availability for built-in areas to predict changes in built-up land space, whether it is still following the carrying capacity or vice versa [3]. A dynamic system model is a form made to mimic a system or image (abstraction) of a complex, dynamic, non-linear system. It has feedback using the modeler's help of simulation tools by applying the modeling cycle [4]. This study is adapted from several studies, namely analyzing land-use changes and predicting future land-use changes affected by sea-level rise. The novelty of this research lies in the characteristics of the area studied, namely Bengkulu City, which is prone to earthquakes, tsunamis, and sea-level rise. The wider the inundation caused by sea-level rise, the more it will affect land use in the area. The objectives of this study are (1) To make a dynamic system model of land use, which is affected by sea-level rise in the coastal city of Bengkulu; (2) To analyze the relationship between built-up land and land availability with sea-level rise in the coastal area of Bengkulu City.

2. Methods/ Materials

2.1 Population growth

Population growth is the change in the number of people in a certain area at a certain time compared to previous times [5]. Population growth is caused by 4 components, namely: birth (fertility), death (mortality), in-migration (in-migration), and out-migration (out-migration). The phenomenon of migration is very coloring in several developing countries, including in various regions in Indonesia, especially when many workers who come from rural areas flow to urban areas, generally because of economic motives.

2.2 Built-up areas

According to the built area, the built-up area is one area that humans form towards their environment [6] according to the built area [7]. The purpose of the distribution of geographic phenomena can be explained as an example of topography, vegetation, geology, and other physical factors in different areas; nothing is the same. The built-up area is one of the human forms of its environment.

2.3 Relationship between population growth and land availability

Land as part of space is the main object in spatial planning. The land is a complex system and has specific characteristics. Rayes [8] argues that the nature of the land will affect water availability, air circulation, development of erosion sensitivity, and availability of nutrients to require a good arrangement. Spatial planning is generally related to land use planning which aims to regulate physical space and determine appropriate activities on the land [9].

The existing population needs space to form built-up land to develop activities and meet their daily needs. Population growth and increased regional economic activity require new space, especially in urban areas. The expansion of land conversion into developed land mainly occurs on the edge of a metropolitan area [10]. It has an impact on the increasing level of land demand resulting in land conversion. This condition encourages an increase in land requirements for settlement and other supporting activities. The rise in land needs impacts changes in land use that are considered less economically valuable, such as agricultural land, forests, and wetlands, into built-up land with high economic value such as settlements or industrial areas [11], [12].

2.4 Dynamic system concept

In general, a dynamic system is defined as a method for studying the working mechanism of a complex, dynamic, non-linear system through the feedback structure between the elements in the system [13]. An active system model is a form that is made to mimic a system or image (abstraction) of a complex, dynamic, non-linear system and has feedback using the help of simulation tools carried out by the modeler by applying the modeling cycle [13]. The Dynamic System Method has various tools in seeing a comprehensive, interconnected situation, including the Causal Loop Diagram (CLD) Model. The Causal Loop Diagram (CLD) model, or what is often known as a cause and effect diagram, is used to solve or prevent problems by looking at every factor related to other factors.

There are four basic concepts in dynamic systems that support the structure and behavior of complex systems. These concepts are: The closed scope What is meant by secure here does not mean there is no interaction with variables from outside the system. Closing is an important variable that creates a cause-and-effect interaction inside the system, and fewer essential variables are outside. The feedback loop as a fundamental component of the system The system's behavior is influenced by the structure of the feedback loop in a closed system. So that the feedback structure is what affects any changes that occur in the system over time, the level and rate (rate) A dynamic system must have two basic types of variables: level and speed. Level, like stock, is the accumulation of elements over time, such as the number of employees or inventory in a warehouse. At the same time, the rate is a variable that affects changes in the value of the level.

The modeling's expertise generally determines the success of dynamic system modeling, both in understanding dynamic system methods, using assistive devices, and following the dynamic system modeling cycle. The dynamic systems modeling cycle is the process steps of creating a dynamic system model simulation and analysis. The dynamic system modeling cycle stages include conceptualization or problem structure, modeling, data input, dimensional consistency testing and simulation, model validation, and sensitivity testing and policy analysis.

2.5 Geographic information system applications

Georafis Information System or Geographic Information System (GIS) is a computer-based information system designed to work using data that has spatial information (spatial reference). This system captures, checks, integrates, manipulates, analyzes, and displays data that spatially refers to earth conditions. GIS technology combines everyday database operations, such as query and statistical analysis, with mapping's unique visualization and analysis capabilities [14].

The form of vector spatial data is based on the coordinate system, while the raster uses pixels. Observation of spatial dynamics is the process of observing differences in the shape of an object or phenomenon by keeping it from a distance at different periods. The phenomenon that occurs here is changes in land cover and land use based on remote sensing data that is multitemporal and has coordinates from the same geographic area so that changes can be identified between two different times [15].

2.6 Method

This research uses quantitative analysis methods and spatial analysis. The research area is the coastal city of Bengkulu based on population growth data and physical data. This research is an illustration of the interaction between sea-level rise and land use on its coast. This phenomenon can be understood through dynamic system modeling, namely prediction models between sea-level promotion and land use, especially for coastal areas in Bengkulu City. This phenomenon is applied in spatial modeling to determine changes in land use that occur temporally and mathematically. This model generates a trend of the relationship between sea-level rise and open land availability, projected to predict the sea-level rise and land use, especially for areas affected by sea-level rise in the future.

Land use can be identified using remote sensing satellite imagery, namely Landsat 8 OLI in 2018 and primary data from various related agencies from 2009 to 2019. Digital elevation model (DEM) and shoreline data derived from remote sensing as well as processed tidal data by using the least square method is used to analyze sea level rise. The spatial model obtained from limiting factors in selecting the location of the built area is then matched with the mathematical prediction results of the dynamic system model based on the relationship between population growth and land use in Bengkulu City, which produces a spatial dynamic prediction model of land use relations in areas affected by sea-level rise. Then the land use prediction map is analyzed with the area affected by sea-level rise and its inundation area. To obtain the relationship between land use and the area affected by sea-level rise, the analysis uses an overlay technique to determine whether the area in use is expanding towards the area affected by sea-level rise or vice versa and to what extent the predicted land use will be affected.

In predicting sea-level rise, tide data can be used. In predicting sea-level rise, it adopts tidal data for the coastal area of Bengkulu City for ten years, from 2009 to 2018. The downloaded tide data is then searched for the correction factor, namely the high difference of mean sea level (MSL) in the coastal areas of Bengkulu. After that, the example from the coastal city of Bengkulu was added with the correction factor. An inundation area map is a visualization of inundated areas due to rising sea levels. The data needed to make inundation maps are the Digital Topography Elevation Model and sea-level rise input. The DEM comes from the ground level elevation points from the RBI map and field measurements which are then interpolated.

2.7 Extraction of land cover information from Landsat 8 OLI Landsat Images

Landsat 8 OLI image processing consists of a pre-processing and image classification using the MLC (Maximum Likelihood Classification) method [16]. This data processing is intended to obtain data on the current area built in 2008 - 2018 and the fraction of temporal land use. The data is used to see the growing trend of the developed region, and then it can be projected in a dynamic system model

2.8 Dynamic system model relationship between population growth and supporting land capacity

In processing this data, the model building is a dynamic spatial model of sea-level rise on land use with the help of Powersim Studio 10 software. The stages in making a model based on the basic framework are as follows:

2.8.1. Understanding and Conceptual Formulation

The first stage identifies problems and finds out why these problems occur by studying actual events in the field [6]. In drafting the concept, the first step is to determine the purpose of making the model. In this study, this model aims to determine the relationship between sea-level rise and land use in the coastal city of Bengkulu. Next, select the model constraints and key variables used. Then do a description of how these variables interact with one another in the model.

2.8.2. Model Making

With a quantitative approach, the model will be in the form of a mathematical, statistical, or computer formula described in a diagrammatic model called a Causal Loop Diagram (CLD). CLD is the disclosure of the occurrence of a cause-and-effect relationship (causal relationship) into a particular image language to understand the concept of the phenomenon's behavior.

2.8.3. Model Simulation

Based on this model or flow diagram, a simulation is carried out to get the results. Simulation can be done by entering data into the model, where calculations are carried out to determine the behavior of symptoms or processes. The effects of the CLD graphics that have been made previously are then simulated in the Powersim Studio software into other, more formal, graphic forms, namely Stock Flow Diagrams (SFD).

2.8.4. Validation of Simulation Results

Validation is carried out to determine the suitability of the simulation results with the simulated symptoms or processes. If the error or deviation of the simulation results from the simulated sign or process is small, the model can be declared good. The model performance validation is done using simple statistical methods, namely the Average Mean Error (AME) between the simulation results and empirical data. The formula used is:

$$AME = |(Si-Ai)| / Ai \quad (1)$$

$$Si = \Sigma SiN \quad (2)$$

$$Ai = \Sigma AiN \quad (3)$$

Information:

A = Actual Value
S = Simulation Value
N = Unit of Time

3. Results and Discussion

In this study, the built-up area was seen based on changes in land cover over ten years adjusted to population data. To obtain information on trends in land cover change, the information was taken from cloud-free images (less than 10%) identified using remote sensing satellite imagery, namely using Landsat 8 OLI TIRS imagery dated April 10, 2008, Landsat 8 OLI TIRS imagery dated January 11, 2013, OLI TIRS 8 Landsat imagery dated 14 September 2018.

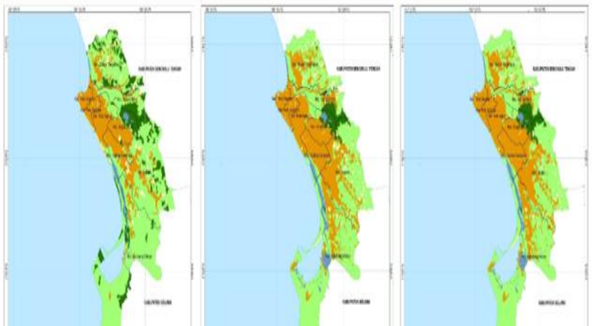

Fig. 1 Maps of land use in Bengkulu City 2013-2018

Changes in land use developed in Bengkulu City are increasing every year following the trend of increasing population. Judging from graph 4.13 above, use for agricultural land has the highest percentage, followed by the percentage of built-up land, non-agricultural land area, water body area, and open land. Based on the data for the three years that have been studied, land use in the form of built-up areas has consistently increased in the past ten years. The built-up area between 2008, 2013, and 2018 was obtained by calculating the mean mean value. The percentage of area change was obtained by calculating the difference between the area in a specific year and the previous year than the land area in the previous year. The prediction results show that the built-up area has increased from 3383.51 Ha to 5485.10 Ha within ten years. Changes in the area of the built area have increased by 5.00% per year. The land-use chart developed in Bengkulu City from 2008 to 2018 is presented in Figure 2.

Simulation of population growth and land availability models was made up to 2300 using a dynamic system model to see the trends of the two variables. From the simulation results, it can be seen that the population prediction generated by the model has an increasing pattern. The regional subsystem built from the initial year of the simulation, namely 2008, continues to increase, however starting from 2100, the growth rate of the built-in area slows down so that a horizontal behavior occurs. It happened because in 2001 the area built was close to the site of the research area.

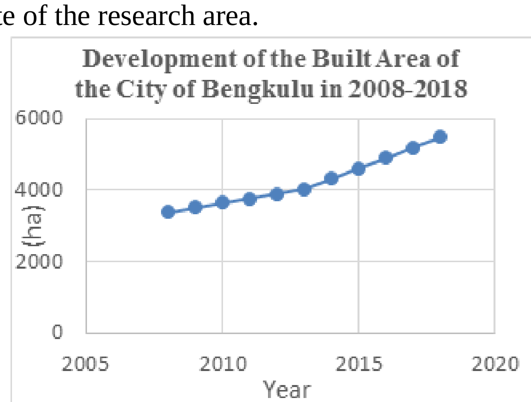

Fig. 2 Development of the built area of the City of Bengkulu in 2008-2018

The land availability variable is also closely related to the built-up area subsystem that was previously simulated. The built-up area subsystem shows the same sigmoid pattern with land availability but has an inverse relationship. In the simulation model results, the built-up area (red graph) continues to increase from year to year, while the area of land availability (green chart) is decreasing. The study area (blue graph) site is constant, especially for the built-in area in the study area; it will reduce as the land conversion occurs into a built-in space for available land.

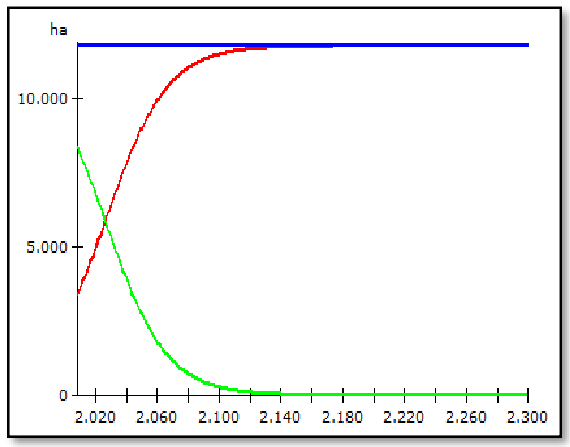

Fig. 3 Graph of relationship between area, built area, and land availability until 2300

This relationship is depicted in Figure 3, which shows the area of the area (blue line) where there is a meeting point of the development line of the built-up area (red line) with a decrease in land availability (green line) in the surrounding research area in 2025. It means that the site of the built-up area occupies 50% of the research area. The intersection of the line between land availability and the built-up area shown in the graph in 2027 shows that in that year, 50% (5994.14 ha) of the available land has been developed from the study area with a population of 476,825 people. Then it increases continuously, approaching the carrying capacity threshold value. The threshold for environmental carrying capacity is in good condition, where a maximum of land can accommodate an area of 70% of its total area [17].

The coastal area of Bengkulu City is an area that is very vulnerable to the phenomenon of sea-level rise because it has a topography that tends to be flat. Based on the analysis of tidal data from the Pulau Baai Tidal Station from the Geospatial Information Agency data from 2008 to 2018, it was processed to obtain the Mean Sea Level (MSL) per year for ten years of observation (2009-2018),

Mean Sea level is the position of the average seawater. On average, it shows a trend of rising sea level in the coastal waters of Bengkulu City, which is around 0.082 m / year. As shown in Figure 4.11, data on the trend of annual sea-level rise.

The problem of sea-level rise is not a single problem that threatens the coastal areas of Bengkulu City. Land subsidence is another threat that must be taken into account. The phenomenon caused by the socio-economic activities of the community related to groundwater discharge causes a relative sea-level rise. Then for the prediction of sea-level rise from 2008 to 2300. The selection of the year of inundation prediction due to sea-level rise was randomly selected to see the difference in inundation area due to sea-level rise; the years analyzed were 2020, 2032, 2050, 2100, 2250, and 2300. The six heights were then entered into the model, and the inundation area map was obtained through Cost Distance analysis using Arc GIS software.

Bengkulu City in the west is directly adjacent to the Indian Ocean. It makes Bengkulu City has a relatively long coastline. Based on the geographical conditions, the coastal area of Bengkulu City is very vulnerable to the impact of sea-level rise because it has flat coastal topography. Sea level rise will reduce coastal areas' function and cause flooding in coastal regions, erosion on sandy beaches, and damage to infrastructure near the coast. In the Sea Level Rise subsystem, if the fraction of sea-level rise is 0.82 cm per year, it will decrease the availability of residential land in a specific area. Land availability will affect the carrying capacity to accommodate its inhabitants. This carrying capacity will affect population decline and population growth, where it will affect land use.

Based on Table 1, the prediction of inundation area, built-up area, and land availability in 2020, 2032, 2050, 2100, and 2250, it can be seen that the location of inundation, sea level, and built-up land continues to increase, it means that these parameters have a relationship is proportional to while the availability of land has decreased inversely with the parameters of inundation area, height, and built-up land. The threshold for environmental carrying capacity is in good condition, where a maximum of land can accommodate size of 70% of its total area [17]. Based on Table 1, the percentage that has not passed the environmental carrying capacity threshold or 70%, namely in 2020 and 2032, with a rate of 43.12% and 58.07%. Meanwhile, the years 2050, 2100, and 2250 have passed the environmental carrying capacity threshold. The results of model validation with the Average Mean Error (AME) between actual data and simulation data in the population subsystem of Bengkulu City from 2008 to 2018 resulted in a deviation of 3.69%, while the validation results for the land use subsystem resulted in a variation of 9.04%.

Table 1. Prediction results of inundation area, built area, and land availability

Year	High (m)	Inundation (ha)	Built up Area (ha)	Land availability (ha)	Percentage (%)
2020	0.10	100.71	4973.73	6692.8	43.12
2032	0.20	108.22	6725.21	4933.81	58.07
2050	0.35	103.57	9034.89	2628.78	77.66
2100	0.76	107.26	11496.32	163.66	98.61
2250	1.97	154.12	11767.11	-153.99	101.31

4. Conclusion

Based on the results of research on the dynamic system model of land use affected by sea-level rise in the coastal area of Bengkulu City, it can be concluded that the dynamic system model shows that the developed land has increased every year, meeting the capacity of the site. The results of model validation with the Average Mean Error (AME) between actual data and simulation data in the population subsystem of Bengkulu City from 2008 to 2018 resulted in a deviation of 3.69%, while the validation results for the land use subsystem resulted in a variation of 9.04%. The area of land use affected in areas prone to sea-level rise has a directly proportional relationship to the year of development of land use. So that the increase of the year, the scope of use, i.e., in areas prone to sea-level rise. It is inversely proportional to the availability of land. As the number of years and land use increases, the availability of land will decrease.

This research can be followed up with a further study in dynamic spatial modeling by increasing the stock associated with sea-level rise. The affected built-up land is described in more detail according to population growth and land availability.

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